DIOXIN-LIKE PCBs

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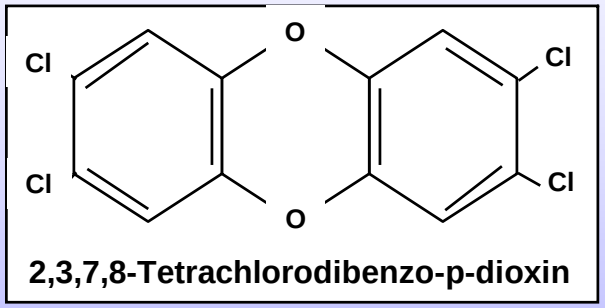
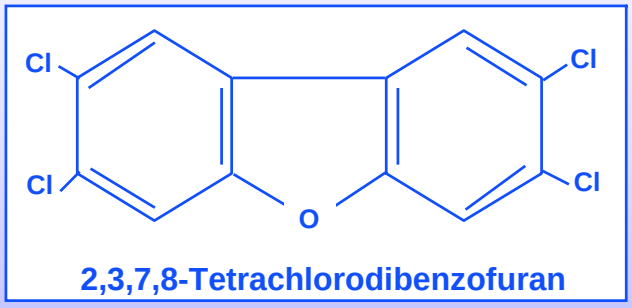
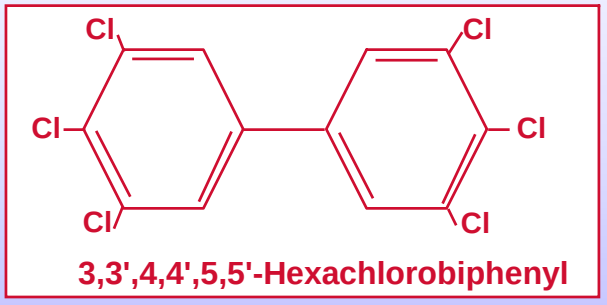
Dioxin-Like Compounds



2,3,7,8-Tetrachlorodibenzo-p-dioxin



2,3,7,8-Tetrachlorodibenzofuran



3,3',4,4',5,5'-Hexachlorobiphenyl

Dioxins
75 congeners
7 toxic

2,3,7,8-TCDD
1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-HxCDD
1,2,3,4,6,7,8-HpCDD
1,2,3,4,6,7,8,9-OCDD

Furans
135 congeners
10 toxic

2,3,7,8-TCDF
1,2,3,7,8-PeCDF
2,3,4,7,8-PeCDF
1,2,3,4,7,8-HxCDF
1,2,3,6,7,8-HxCDF
1,2,3,7,8,9-HxCDF
2,3,4,6,7,8-HxCDF
1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-HpCDF
1,2,3,4,6,7,8,9-OCDF

PCBs
209 congeners
12 toxic

3,3',4,4'-TeCB
3,3',4,4',5-PeCB
3,3',4,4',5,5'-HxCB
Plus 8 others

Toxic Equivalency (TEQ)

Reassessment Chapter Summarizes Scientific Support

- *Based on inspection of multiple endpoints and/or receptor binding (WHO criteria)*
- *Fundamental to evaluation of this group of compounds*
- *Having growing empirical basis and being theoretically sound*
- *WHO_{98} internationally accepted*

Five Compounds Make up About 80% of the Total TEQ in Human Tissue

- **Four of 17 Toxic CDD/CDF Congeners**
- **One of the 12 toxic PCBs**
  - ***2,3,7,8-TCDD***
  - ***1,2,3,7,8-PCDD***
  - ***1,2,3,6,7,8-HxCDD***
  - ***2,3,4,7,8-PCDF***
  - ***PCB 126***

Body Burden Best Dose Metric (Ng/Kg BW)

- *Accounts for differences in half-life*
- *Results in strong agreement between human and animal data*
- *Adopted by WHO, EC, HHS*

Toxic Equivalency (TEQ)

- ***Fundamental to evaluation of this group of compounds***
- ***Based on inspection of multiple endpoints and/or receptor binding (WHO criteria)***
- ***Reassessment Chapter Summarizes Scientific Support***
- ***WHO_{98} internationally accepted***

Dioxins and Human Carcinogenicity

2,3,7,8-TCDD	➔	**Carcinogenic to humans**
Other dioxin-like compounds	➔	**Likely to be carcinogenic**
Complex Environmental Mixtures	➔	**Likely to be carcinogenic**

Based on:

- **Unequivocal animal carcinogen**
- **Limited human information (epidemiological/other)**
- **Mechanistic plausibility**

Cancer potency increasingly focusing on human studies

Note: (IARC) classified TCDD as a Category 1, “Known” human carcinogen. DHHS 9th Report on Carcinogens (ROC) the same

Dioxin-like Compounds are Noncancer Toxicants in Animals and Humans

- Developmental Toxicity
  - ***Targets:***
    - Developing Immune System
    - Developing Nervous System
    - Developing Reproductive System
- Immunotoxicity
- Endocrine Effects
- Chloracne
- Others

Current Dioxin Exposure

➔ ***Environmental Exposure***

- **~ 1 PG TEQ/Kg/Day (PCDDs/PCDFs/PCBs)**
- **Possible Higher Intake Populations**
  - **Nursing infants**
  - **Fatty Diet**
  - **Some subsistence fishermen and farmers in proximity to contamination**

Body Burden Best Dose Metric
(Ng/Kg BW)

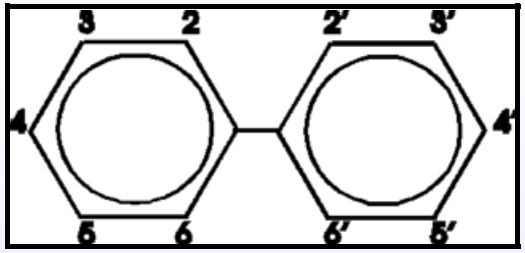
- *Accounts for differences in half-life*
- *Results in strong agreement between human and animal data*
- *Adopted by WHO, EC, HHS*

Risks To General Population From Exposure to Dioxins

- Upper Bound Cancer Risk From Mean General Population Exposure --- $1x10^{-3}$
- Adverse Non-cancer Effects Observed Within 10X of Background

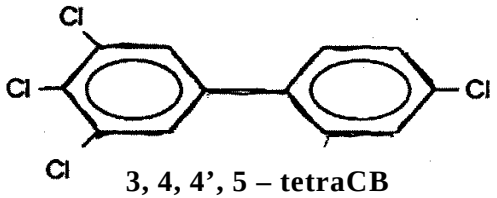
How dioxin-like compounds are addressed in the dioxin reassessment

- What are “dioxin-like” PCBs
- The concept of TCDD TEQ for PCBs
- Environmental levels
- Levels in food
- Daily intake
- Conclusions

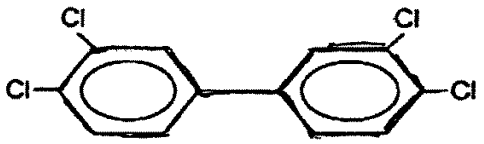


- *Meta positions* - chlorine atoms in positions 3, 3', 5, and 5'
- *Para positions* - chlorine atoms in positions 4 and 4‘
- *Ortho positions* – 2,2’,6,6’

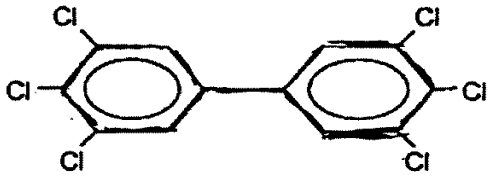
The PCBs assume a dioxin-like structure when chlorines occupy:
(a) usually no more than one of the ortho positions;
(b) both para positions;
(c) at least two meta positions;
(d) the structure is not hindered from assuming the preferred planar configuration.



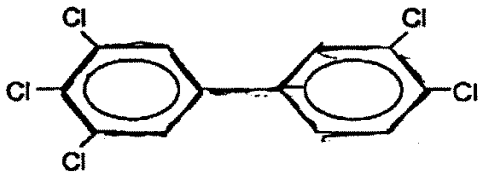
3, 4, 4', 5 – tetraCB



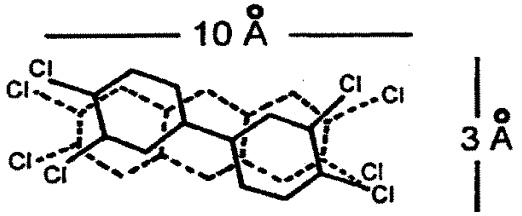
3, 3', 4, 4' – tetraCB



3, 3', 4, 4', 5, 5' -hexaCB



3, 3', 4, 4', 5 -pentaCB



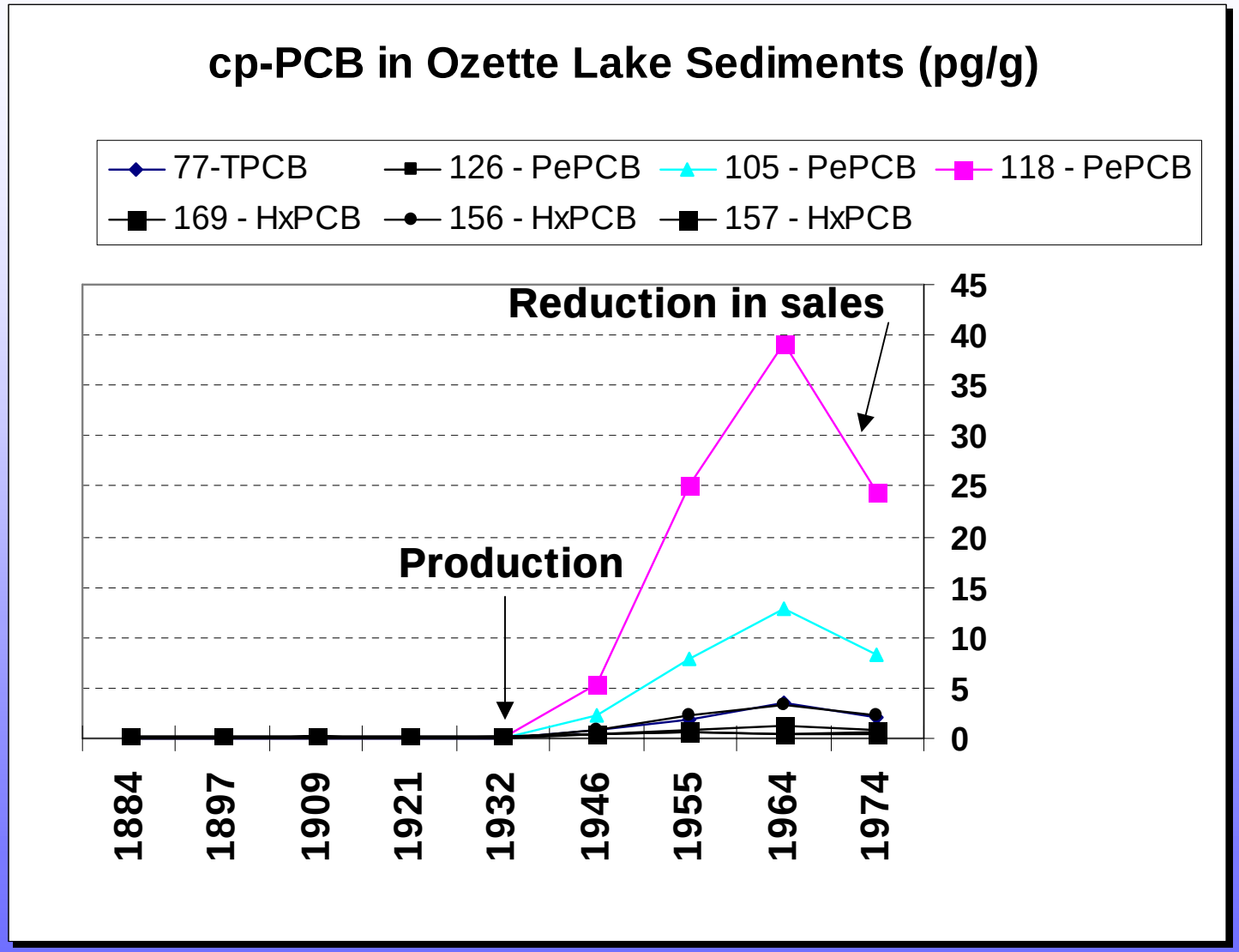
Dioxin-Like = Co-Planar PCB Congeners

Source: NRC (2000)

WHO (1998) Established Toxic Equivalency Factors (TEFs) for 12 PCBs (Humans)

Chemical Structure	IUPAC Number	TEF
3,3',4,4'-TeCB	PCB-77	0.0001
3,4,4',5-TeCB	PCB-81	0.0001
2,3,3',4,4'-PeCB	PCB-105	0.0001
2,3,4,4',5-PeCB	PCB-114	0.0005
2,3',4,4',5-PeCB	PCB-118	0.0001
2',3,4,4',5-PeCB	PCB-123	0.0001
3,3',4,4',5-PeCB	PCB-126	0.1
2,3,3',4,4',5-HxCB	PCB-156	0.0005
2,3,3',4,4',5'-HxCB	PCB-157	0.0005
2,3',4,4',5,5'-HxCB	PCB-167	0.00001
3,3',4,4',5,5'-HxCB	PCB-169	0.01
2,3,3',4,4',5,5'-HpCB	PCB-189	0.0001

Environmental Time-Trends from EPA Sediment Core Study



Source: Cleverly et al. (1997)

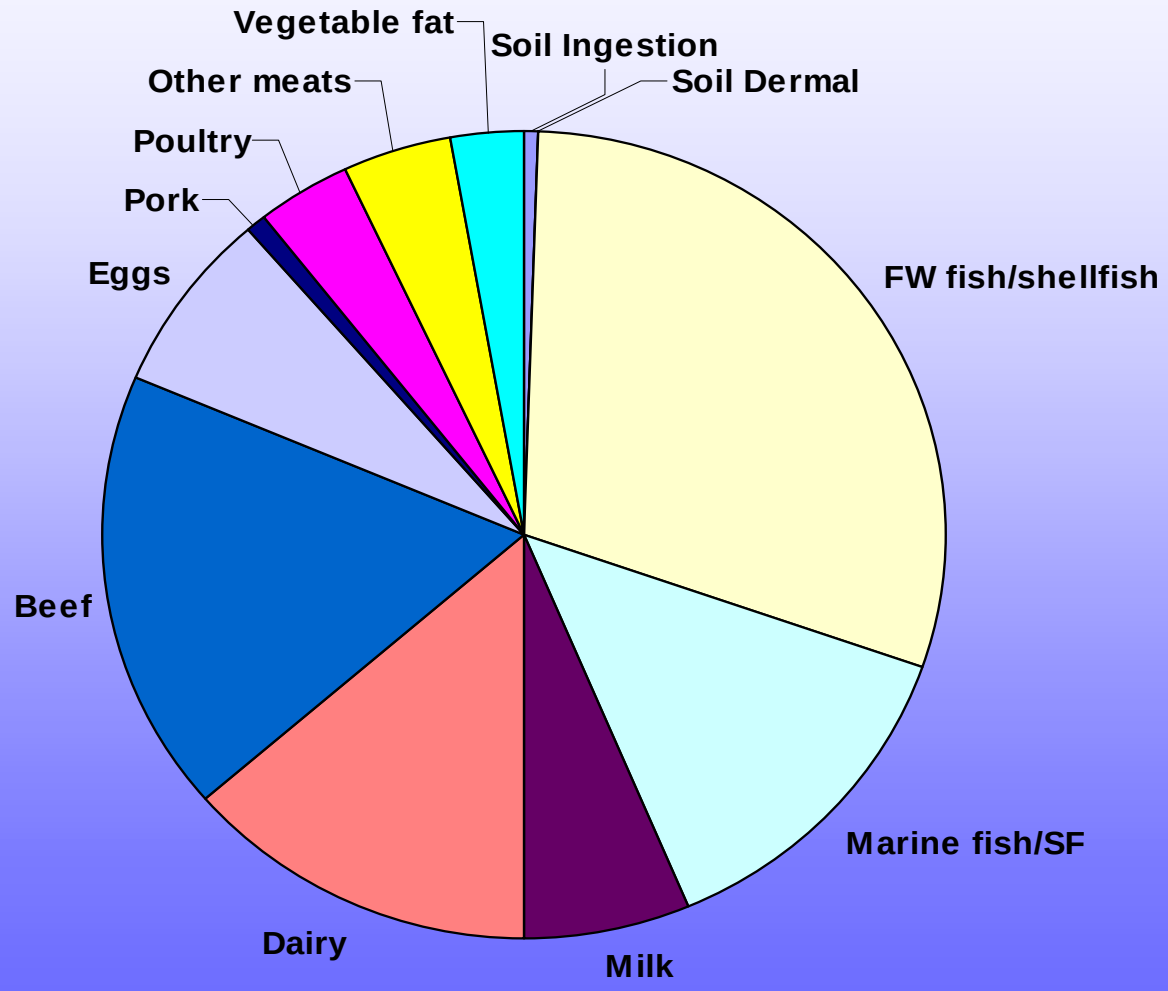
Mean levels in environmental media (ppt except air pg/m^3)

Media	Dioxin TEQ	PCB TEQ
Urban soil	9.3 (270)	2.3 (99)
Rural soil	2.7 (354)	0.59 (62)
Sediment	5.3 (11)	0.53 (11)
Urban air	0.12 (112)	0.0009
Rural air	0.013 (60)	0.0007 (53)

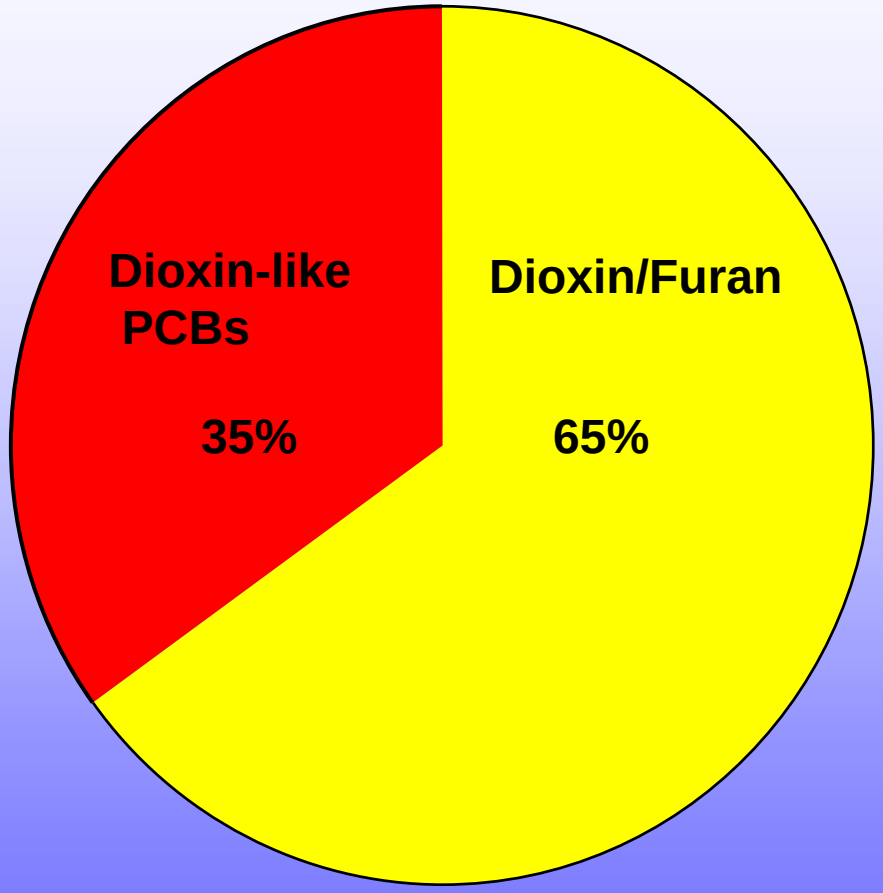
Mean levels in human foods (ppt whole wt)

Food	Dioxin TEQ	PCB TEQ
Milk	0.018 (8 c)	0.0088 (8 c)
Dairy	0.12 (8 c)	0.058 (8 c)
Eggs	0.081 (15 c)	0.10 (24)
Beef	0.18 (63)	0.084 (63)
Pork	0.28 (78)	0.0093 (78)
Poultry	0.068 (78)	0.026 (78)
Veg. fats	0.056 (30)	0.037 (5)

Intake of Dioxin-Like PCBs



Contribution of dioxin-like PCBs to total daily intake



Total daily intake = 0.94 pg WHO-TEQ/kg-d

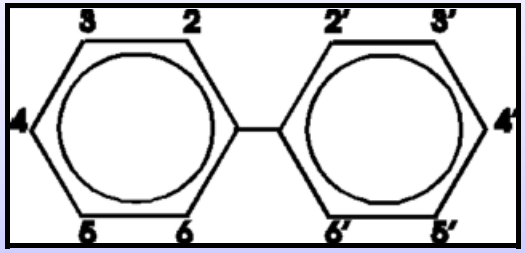
Conclusions

- Dioxin-like PCBs are co-planar; have a geometric configuration like 2,3,7,8-TCDD
- Dioxin Reassessment adapts the concept of Toxic Equivalence to TCDD (using the WHO-1998 procedure) when evaluating risks

Conclusion...continued

- The Dioxin Reassessment estimates total daily intake of dioxin-like PCBs = 0.33 pg TEQ/kg-d
- Daily intake of dioxin-like PCBs adds about 1/3 more to total estimated dioxin TEQ.
- Most exposure of dioxin-like PCBs is from the consumption of freshwater fish and shell fish.

Chemistry



- PCBs are a class of aromatic hydrocarbons consisting of a biphenyl nucleus (2 hexagonal rings of carbon atoms connected by carbon-carbon bonds) on which one to ten of the hydrogen atoms can be replaced with chlorine atoms.
- 209 congeners; 10 homologue groups.
  - *Meta positions* - chlorine atoms in positions 3, 3', 5, and 5'
  - *Para positions* - chlorine atoms in positions 4 and 4‘
  - *Ortho positions* – 2,2’,6,6’

Category	*Number Comprising the Category*
Congener	209 distinct PCB compounds
Homologue	10 groups based on number of chlorine atoms
Isomers	1- 46 distinct PCB compounds with similar molecular weight
Monochlorobiphenyl	3
Dichlorobiphenyl	12
Trichlorobiphenyl	24
Tetrachlorobiphenyl	42
Pentachlorobiphenyl	46
Hexachlorobiphenyl	42
Heptachlorobiphenyl	24
Octachlorobiphenyl	12
Nonochlorobiphenyl	3
Decachlorobiphenyl	1

Production

- Commercially produced as complex mixtures from 1929 through 1976.
  - Swann Chem (1929), Anniston, AL; Then Monsanto (1935)
- Monsanto used trade name Aroclor.
  - Except for 1016, the last two numbers = nominal percent chlorine present.
- Congeners are colorless, odorless crystals; but as commercial mixtures, clear viscous liquids. The more chlorines, the more viscous, e.g.,Aroclor 1260 is a sticky resin.

Production

- Not found in nature; synthesized by direct chlorination of biphenyl with chlorine gas under pressure with an iron chloride catalyst
- 130 congeners have been detected in Aroclors; controlled by temp., pressure and time of reaction
- About 700,000 metric tons produced in the U.S (93% by Monsanto)
- Worldwide production: about 1.5 million tons

Usage of PCBs

Category	Type of Product	Total Use
Closed electrical systems	Transformers, capacitors, electrical insulating and cooling applications	61% before 1971 100% after 1971
Nominally closed systems	Hydraulic fluids, heat transfer fluids, lubricants	13% before 1971 0% after 1971
Open-end applications	Plasticizers, surface coatings, ink and dye carriers, adhesives, pesticide extenders, carbonless copy paper, dyes	26% before 1971 0% after 1971

Source: NRC (2000)

A few facts about Aroclors

Aroclor Trade Name	Approx. Mol. wt.	Wt. Percent Chlorine	Boiling point (°C)	% U.S. Production 1957-1977
1016	257.9	40	325-356	12.88
1221	200.7	21	275-320	0.96
1232	232.2	32	290-325	0.24
1242	266.5	42	325-366	51.76
1248	299.5	48	340-375	6.76
1254	328.4	54	365-390	15.73
1260	357.7	60	385-420	10.61
1262	389	62	390-425	0.83
1268	453	68	435-450	0.33

Typical PCB Homologue Composition (% wt) of Five PCB Aroclors

PCB Homologue	Aroclor 1016 (%)	Aroclor 1242 (%)	Aroclor 1248 (%)	Aroclor 1254 (%)	Aroclor 1260 (%)
Mono-CB	0.7	0.8	0	0	0
Di-CB	17.5	15.0	0.4	0.2	0.1
Tri-CB	54.7	44.9	22.0	1.3	0.2
Tetra-CB	26.6	32.6	56.6	16.4	0.5
Penta-CB	0.5	6.4	18.6	53.0	8.6
Hexa-CB	0	0.3	2.0	26.8	43.4
Hepta-CB	0	0	0.6	2.7	38.5
Octa-CB	0	0	0	0	8.3
Nona-CB	0	0	0	0	0.7
Deca-CB	0	0	0	0	0

Source: Frame (1996, 1999)

Estimated Historical Environmental Release of PCBs in the U.S.

Year	Aroclor 1016 (metric tons)	Aroclor 1242 (metric tons)	Aroclor 1248 (metric tons)	Aroclor 1254 (metric tons)	Aroclor 1260 (metric tons)	Total PCB Releases (metric tons)
1930-56	0	8,486	2,447	2,269	1,614	14,817
1957	0	903	319	307	423	1,952
1958	0	649	483	416	355	1,903
1959	0	1,042	724	518	507	2,792
1960	0	1,340	556	449	540	2,885
1961	0	1,852	792	587	611	3,841
1962	0	1,811	659	554	571	3,594
1963	0	1,655	935	529	682	3,801
1964	0	2,085	980	555	755	4,375
1965	0	2,689	1,025	660	497	4,872
1966	0	3,180	876	566	472	5,094
1967	0	3,376	814	525	504	5,219
1968	0	3,533	853	733	433	5,552
1969	0	4,165	993	985	452	6,596
1970	0	4,569	697	1,168	474	6,907
1971	76	1,466	51	325	121	1,963
1972	474	22	0	104	9	135
1973	534	141	0	181	0	322
1974	498	141	0	140	0	281
TOTALS	1,582	43,103	13,205	11,572	9,019	76,898
% of Total	2.1%	56.1%	17.2%	15.0%	11.7%	100.0%

Source: USEPA (1976)

Estimated Global Environmental Loading (1985)

Environment	PCB Load (metric tons)	Percentage of PCB Load	Percentage of World Production
Terrestrial and Coastal			
Air	500	0.13	
River and Lake Water	3,500	0.94	
Seawater	2,400	0.64	
Soil	2,400	0.64	
Sediment	130,000	35	
Biota	4,300	1.1	
Total (A)	143,000	39.00	
Open Ocean			
Air	790	0.21	
Seawater	230,000	61	
Sediment	110	0.03	
Biota	270	0.07	
Total (B)	231,000	61.00	
Total Load in Environment (A+B)	374,000	100	31
Degraded and Incinerated	43,000		4
Land-stocked[a]	783,000		65
World Production	1,200,000		100

Source: Tanabe (1988); note that a world production of 1.2-million metric tons is assumed by Tanabe (1988). DeVoogt and Brinkman (1989) estimated worldwide

Environmental Fate/Transport Alters PCB Mixtures

- Solubility in water
- Vapor Pressure
- Volatilization
- Biodegradation potential
- Bioaccumulation
- Weathering

Congener mixtures in environment

Generalizations of fate properties of PCBs

Physical/chem Properties	Change with > Cl
Boiling point	Increases
Vapor pressure	Decreases
Solubility	Decreases
Octanal/Water Part	Increases
Lipophicity	Increases
Persistence	Increases

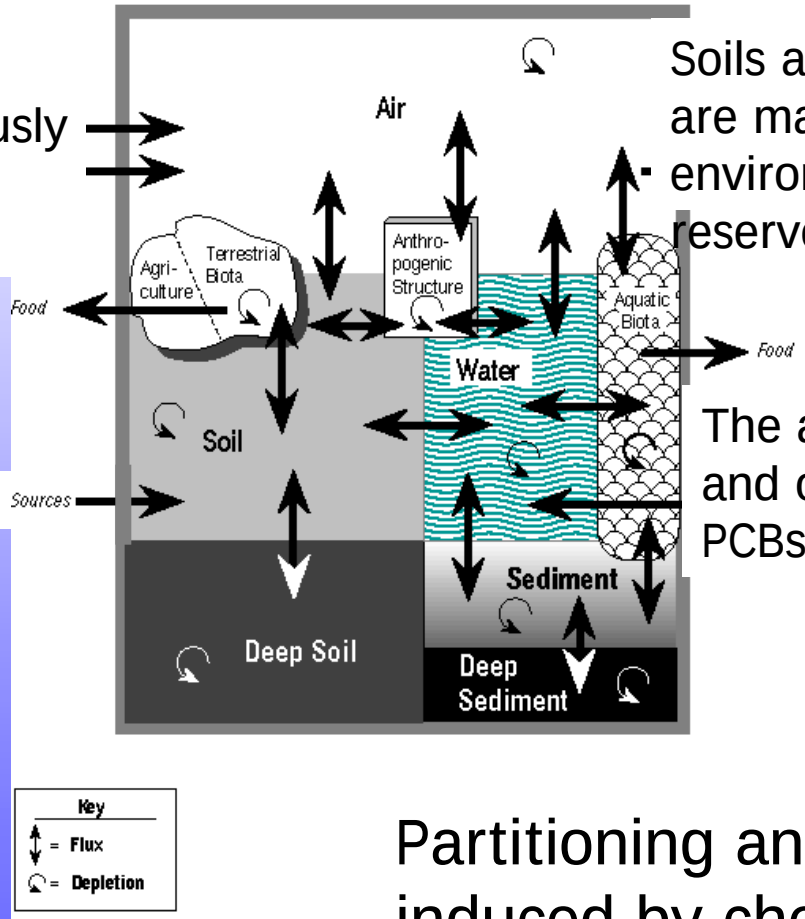
Generalized Physical-Chemical Properties

PCB	BP (^{0}C)	VP (Pa @ 25^{o}C)	Sol (g/m^3)	Log K_{ow}	BCF in Fish	Evap (g/(m^2 h)
Mono	285	1.1	4.0	4.7	2500	0.25
Di	312	0.24	1.6	5.1	6300	0.065
Tri	337	0.054	0.65	5.5	2E+04	0.017
Tetra	360	0.012	0.26	5.9	4E+04	4E-03
Penta	381	3E-03	0.099	6.3	1E+05	1E-03
Hexa	400	6E-03	0.038	6.7	3E+05	3E-04
Hepta	417	2E-04	0.014	7.1	6E+05	6E-05
Octa	432	3E-05	6E-03	7.5	2E+06	2E-05
Nona	445	6E-06	2E-03	7.9	4E+06	4E-06
Deca	456	2E-06	8E-04	8.3	1E+07	9E-07

Source: Erickson (1997)

The environmental distribution and partitioning of PCBs

Major source is the environmental cycling of PCBs previously introduced into the environment



Soils and Sediments are major environmental reservoirs

PCBs have a strong affinity for sorption into organic carbon

The atmosphere and oceans distribute PCBs globally

Partitioning and movement induced by chemical/physical characteristics

Biodegradation of PCB congeners

- Dechlorination by aerobic and anaerobic bacteria. Overall these are slow processes.
- The light congeners… e.g., Mono, di and tri – PCBs generally biodegrade aerobically
- The heavier congeners,e.g., Tetra and Penta PCBs generally biodegrade anaerobically
- Studies have shown that anaerobic process can reduce total Cl of PCBs present by 33 – 36% (Sokol et al., 1998) over several decades.
- Temperature and PCB concentration dependent.

Biodegradation..continued

- The rate of anaerobic dechlorination depends on *meta* and *para* removal
  - Process P is removal of *para* chlorines with at least one adjacent chlorine (Tetra – Hepta PCBs)
  - Process N is removal of *meta* chlorines with at least one adjacent chlorine (nearly all Hexa and Hepta PCB congeners are affected resulting in production of light MW congeners.
- The light MW PCB congeners are subject to aerobic microbial degradation – oxidatively mineralize to carbon dioxide and water.

Volatilization (generalizations)

- Evaporative loss of PCBs from soils and water bodies to the atmosphere
- Lighter MW PCB congeners having higher VP and lower Henry's Law constants, e.g., mono, di, tri PCBs

Bioaccumulation (generalizations)

- Accumulation from sediment to plankton and fish is largely determined by degree of PCB chlorination.
- Plankton and fish are enriched in high K_{ow} PCB congeners, and depleted in low K_{ow} PCBs
- Maximum bioaccumulation occurs for Penta, Hexa and Hepta PCB congeners
- Enrichment of Penta, Hexa and Hepta congeners and depletion of Tri PCBs with > trophic level

Conclusions

- Occurrences of PCB congeners in environmental media and biota are largely a consequence of historic source releases.
- Environmental fate processes and environmental cycling alter PCB congener profiles with time

Conclusions...continued

- Mono, di and tri chlorinated PCBs tend to volatilize from soils and water bodies to air, leaving the higher MW compounds.
- Mono, di and tri chlorinated PCBs may aerobically degrade in freshwater sediments.
- Tetra, Penta, Hexa and Hepta PCBs are subject to anaerobic dechlorination in sediments in either the *meta* or *para* positions.

Conclusions....continued

- Bioaccumulation and biotransformation changes the pattern and composition of PCB mixtures present in living organisms relative to the pattern in soils and sediments…the higher chlorinated PCBs are enriched (Penta, Hexa and Hepta PCBs) while lower chlorinated species are depleted.

Conclusions...continued

- As a result of environmental fate processes, the composition of PCB congener mixtures that are present in the environment are significantly different from that of the original Aroclor formulations that were once discharged into the environment.
- As a result of low VP and environmental fate and transport processes, PCBs are present in the global environment.

Dioxins and Human Carcinogenicity

2,3,7,8-TCDD	➔	**Carcinogenic to humans**
Other dioxin-like compounds	➔	**Likely to be carcinogenic**
Complex Environmental Mixtures	➔	**Likely to be carcinogenic**

Based on:

- **Unequivocal animal carcinogen**
- **Limited human information (epidemiological/other)**
- **Mechanistic plausibility**

Cancer potency increasingly focusing on human studies

Note: (IARC) classified TCDD as a Category 1, “Known” human carcinogen. DHHS 9th Report on Carcinogens (ROC) the same

Quantitative estimate of cancer risk

- **Cancer slope factor is revised upward by a factor of ~6 over the 1985 EPA value**
- **Cancer risks to the general population may exceed 10^{-3} (1 in 1,000) from background (dietary) exposure but are likely to be less and may even be zero for some individuals**

Body Burdens Associated With Non-Cancer Effects

	Ng/Kg	MOE*
➔ Adverse Effects		
➢ *Developmental neurotoxicity:*	22	4
➢ *Developmental/reproductive toxicity:*	0.7 - 42	0.1 - 8
➢ *Developmental immunotoxicity:*	50	10
➢ *Adult immunotoxicity:*	1.6 - 12	0.3 - 2
➢ *Endometriosis:*	22	4
➔ Biochemical Effects		0.6 - 16
➢ *CYP1A1 Induction:*	0.6 - 33	0.1 - 7
➢ *CYP1A2 Induction:*	2.1 - 83	0.4 - 17

***MOE = effect level / current average U.S. background body burdens of 5 Ng/Kg**

Inventory of Sources of Dioxin in the United States-May, 2000	*1987 Emissions (g TEQdf-WHO98/yr)*	*1995 Emissions (g TEQdf-WHO98/yr)*	*2002/4 Emissions (g TEQdf-WHO98/yr)*
Municipal Solid Waste Incineration, air	8877.0	1250.0	*12.0*
Backyard Barrel Burning, air	604.0	628.0	*628.0*
Medical Waste Incineration, air	2590.0	488.0	*7.0*
Secondary Copper Smelting, air	983.0	271.0	*5.0*
Cement Kilns (haz waste), air	117.8	156.1	*7.7*
Sewage Sludge/land applied, land	76.6	76.6	*76.6*
Residential Wood Burning, air	89.6	62.8	*62.8*
Coal-fired Utilities, air	50.8	60.1	*60.1*
Diesel Trucks, air	27.8	35.5	*35.5*
Secondary Aluminum Smelting, air	16.3	29.1	*29.1*
2,4-D, land	33.4	28.9	*28.9*
Iron Ore Sintering, air	32.7	28.0	*28.0*
Industrial Wood Burning, air	26.4	27.6	*27.6*
Bleached Pulp and Paper Mills, water	356.0	19.5	*12.0*
Cement Kilns (non-haz waste), air	13.7	17.8	*17.8*
Sewage Sludge Incineration, air	6.1	14.8	*14.8*
EDC/Vinyl chloride, air	NA	11.2	*11.2*
Oil-fired Utilities, air	17.8	10.7	*10.7*
Crematoria, air	5.5	9.1	*9.1*
Unleaded Gasoline, air	3.6	5.9	*5.9*
Hazardous Waste Incineration, air	5.0	5.8	*3.5*
Lightweight ag kilns, haz waste,air	2.4	3.3	*0.4*
Kraft Black Liquor Boilers, air	2.0	2.3	*2.3*
Petrol Refine Catalyst Reg., air	2.2	2.2	*2.2*
Leaded Gasoline, air	37.5	2.0	*2.0*
Secondary Lead Smelting, air	1.2	1.7	*1.7*
Paper Mill Sludge, land	14.1	1.4	*1.4*
Cigarette Smoke, air	1.0	0.8	*0.8*
EDC/Vinyl chloride, land	NA	0.7	*0.7*
EDC/Vinyl chloride, water	NA	0.4	*0.4*
Boilers/industrial furnaces, air	0.8	0.4	*0.4*
Tire Combustion , air	0.1	0.1	*0.1*
Drum Reclamation, air	0.1	0.1	*0.1*
TOTALS	13,995	3,252	*1,106*
Percent Reduction from 1987		77%	92%

updated 3/08/01

Inventory of Sources of Dioxin in the United States- Sept, 2000 draft	1987 Emissions (g TEQdf-WHO98/yr)	1995 Emissions (g TEQdf-WHO98/yr)	*% Total 1995*
Municipal Solid Waste Incineration, air	8877.0	1250.0	38%
Backyard Barrel Burning, air	604.0	628.0	19%
Medical Waste Incineration, air	2590.0	488.0	15%
Secondary Copper Smelting, air	983.0	271.0	8%
Cement Kilns (haz waste), air	117.8	156.1	5%
Sewage Sludge/land applied, land	76.6	76.6	2%
Residential Wood Burning, air	89.6	62.8	2%
Coal-fired Utilities, air	50.8	60.1	2%
Diesel Trucks, air	27.8	35.5	1%
Secondary Aluminum Smelting, air	16.3	29.1	1%
2,4-D, land	33.4	28.9	1%
Iron Ore Sintering, air	32.7	28.0	1%
Industrial Wood Burning, air	26.4	27.6	1%
Bleached Pulp and Paper Mills, water	356.0	19.5	1%
Cement Kilns (non-haz waste), air	13.7	17.8	1%
Sewage Sludge Incineration, air	6.1	14.8	0%
EDC/Vinyl chloride, air	NA	11.2	0%
Oil-fired Utilities, air	17.8	10.7	0%
Crematoria, air	5.5	9.1	0%
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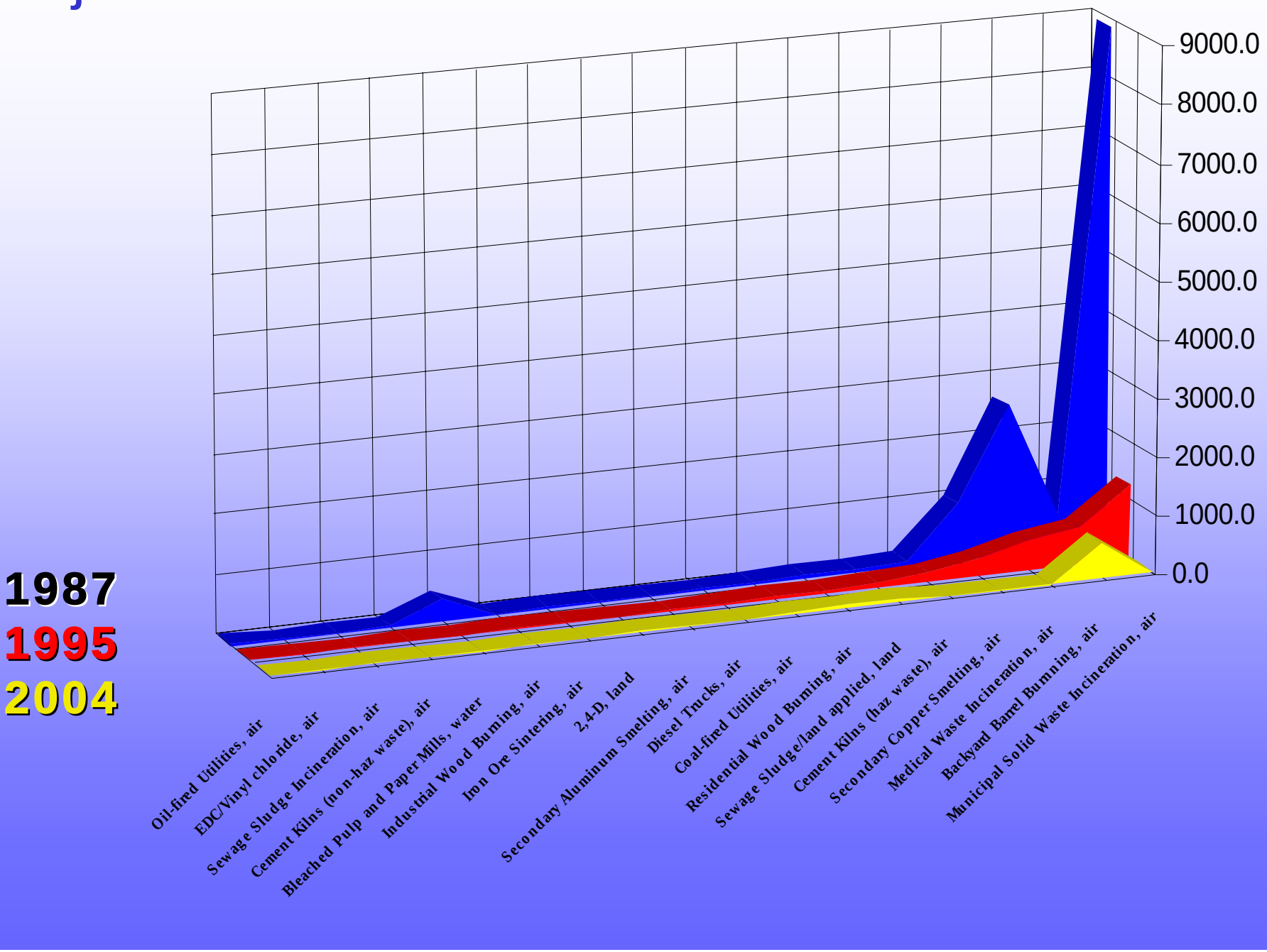
Kraft Black Liquor Boilers, air	2.0	2.3	0%
Petrol Refine Catalyst Reg., air	2.2	2.2	0%
Leaded Gasoline, air	37.5	2.0	0%
Secondary Lead Smelting, air	1.2	1.7	0%
Paper Mill Sludge, land	14.1	1.4	0%
Cigarette Smoke, air	1.0	0.8	0%
EDC/Vinyl chloride, land	NA	0.7	0%
Primary Copper, air	0.5	0.5	0%
EDC/Vinyl chloride, water	NA	0.4	0%
Boilers/industrial furnaces	0.8	0.4	0%
Tire Combustion, air	0.1	0.1	0%
Drum Reclamation, air	0.1	0.1	0%
TOTALS	13,995	3,252	
Percent Reduction from 1987		77%	
updated 3/08/01			

Major US Dioxin Sources



Poorly Characterized Sources

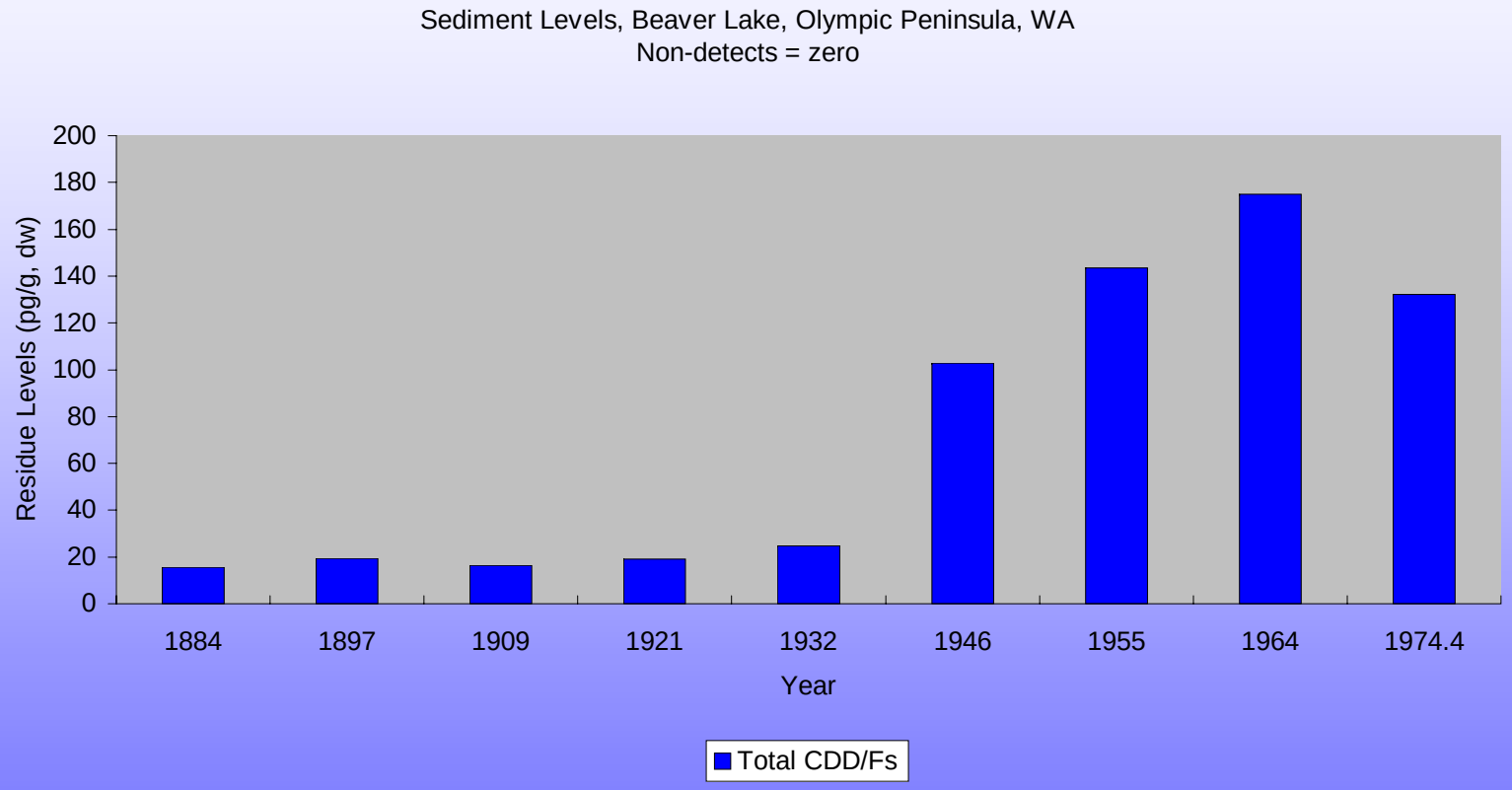
- **Secondary steel electric arc furnaces**
- **Coke production**
- **Ceramic manufacturing**
- **Clay processing**
- **Ferrous and non-ferrous foundries**
- **Asphalt mixing plants**
- **Primary magnesium**
- **TiO_2**
- **Wood stoves**
- **Forest fires**
- **Brush fires**
- **Range fires**
- **Ag burning**
- **Landfill fires**
- **Structural fires**
- **Landfill flares**
- **Rural soil erosion to water**
- **Urban runoff to surface water**
- **Utility poles and storage yards**
- **Landfill fugitive emissions**
- **Transformer storage yards**

POTENTIAL SIGNIFICANCE OF UNCONTROLLED COMBUSTION

If other uncontrolled combustion sources, either collectively or individually, are of the same magnitude as barrel burning …

Then releases from uncontrolled combustion may have played a much more important role historically than indicated by current inventories based primarily on industrial sources.

20th Century Trend



UNCONTROLLED COMBUSTION

In non-industrial and developing countries, uncontrolled burning appears to be much more prevalent and is likely to dominate release for these countries and possibly total global releases.

What is less clear is whether uncontrolled combustion in non-industrialized countries can result in environmental or exposure levels similar to those found in industrialized nations.

Progress in characterizing these sources is of immediate policy relevance for both developed and developing nations.

Reservoir Sources

Old releases of dioxins that are temporarily stored in environmental compartments to later be reintroduced into the circulating environment:

- **Soil**
- **Sediment**
- **Biota**
- **Materials**

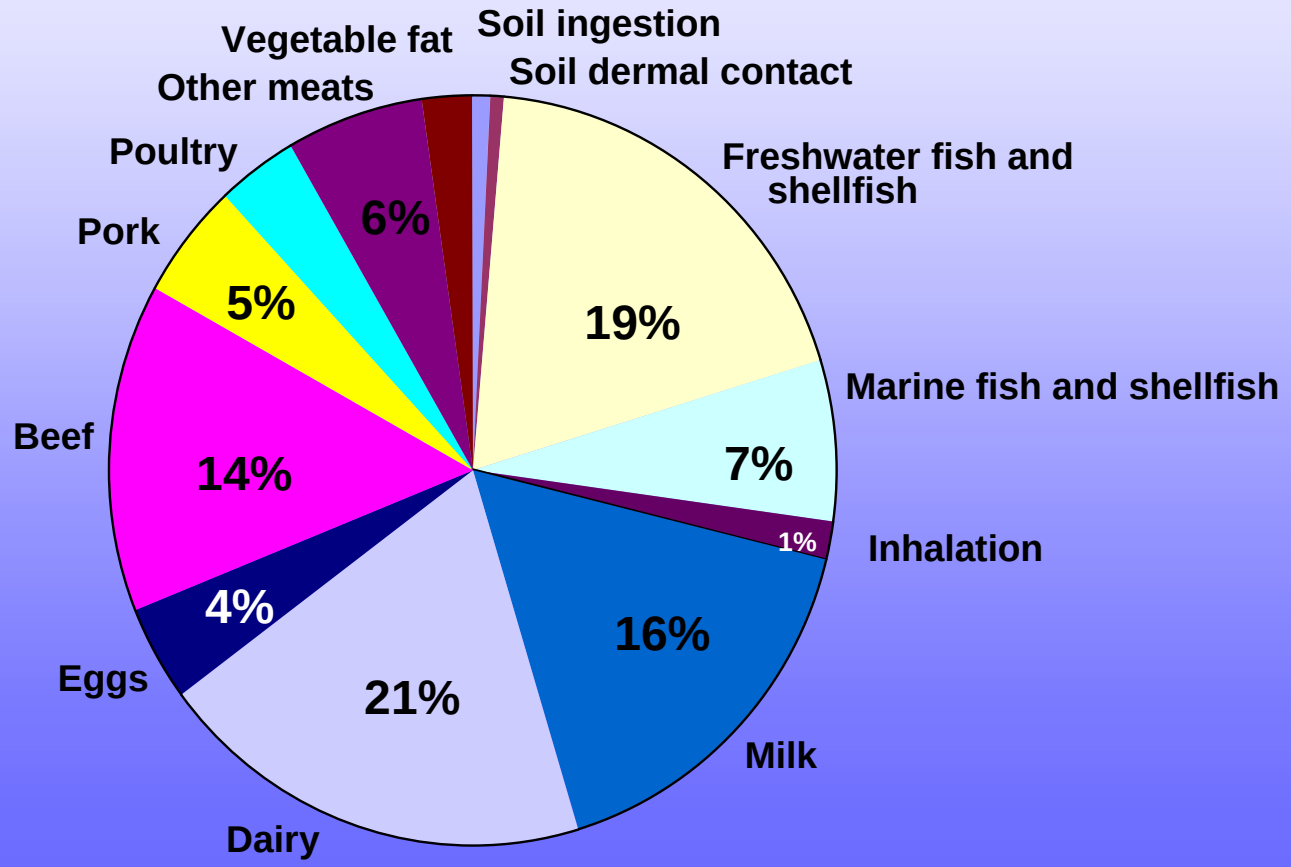
Reservoirs contribute as much as 50% to general population exposure.

Reservoir Sources

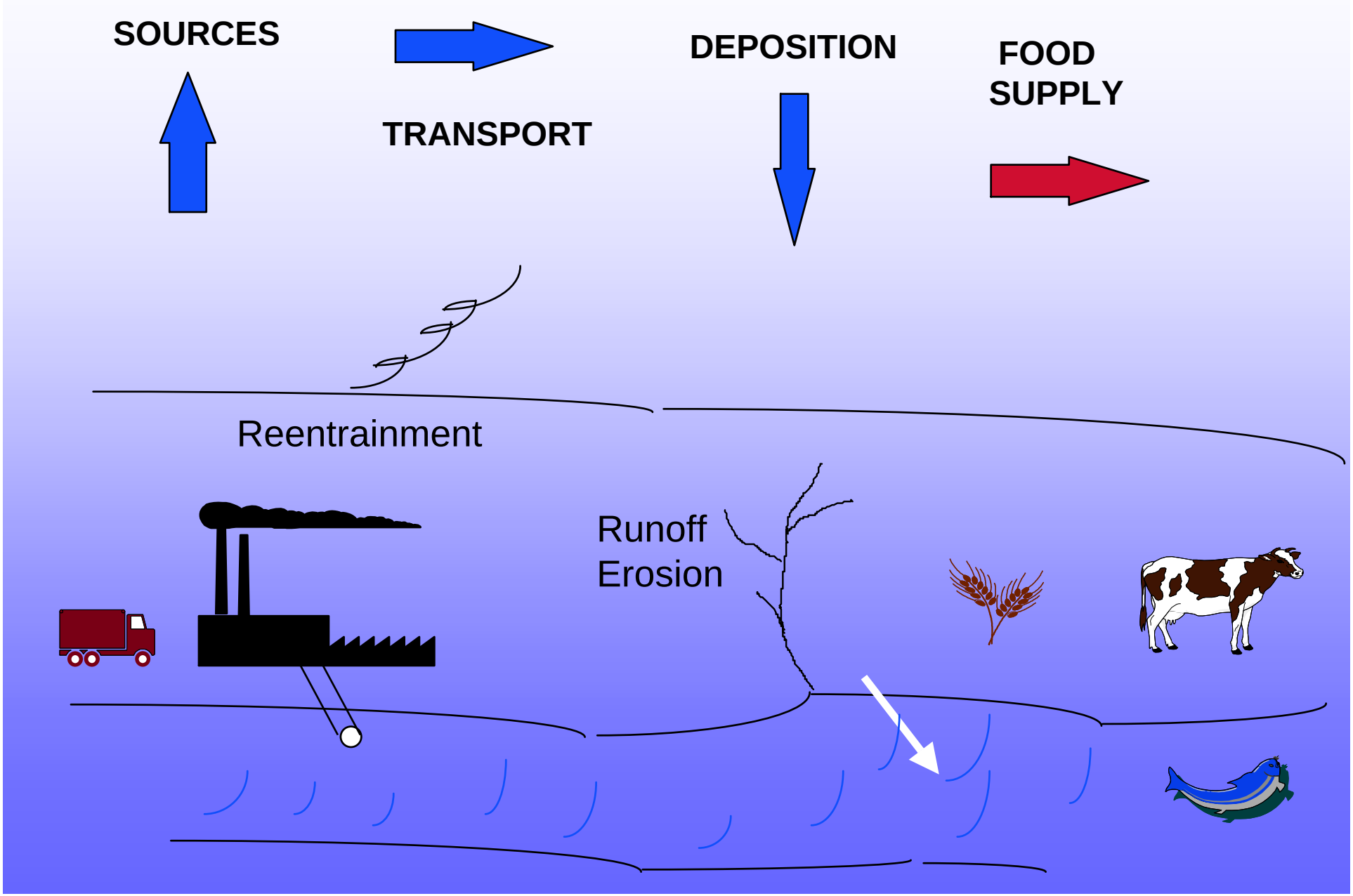
- **Given the magnitude of past releases and the persistence of dioxin-like compounds, it seems likely that existing reservoir sources could sustain their current level of exposure contribution for years/decades**.
- **If this is the case, then, even if we could eliminate all contemporary sources, exposure and subsequent risks could be sustained at about 50% of current levels for some time.**
- **Better quantifying the current exposure contribution made by reservoir sources, and gaining a better understanding of continued strength of these sources, would do much to facilitate long-term strategic planning for dioxin risk management.**

U.S. Adult Average Daily Intake of CDDs/CDFs/ Dioxin - Like PCBs

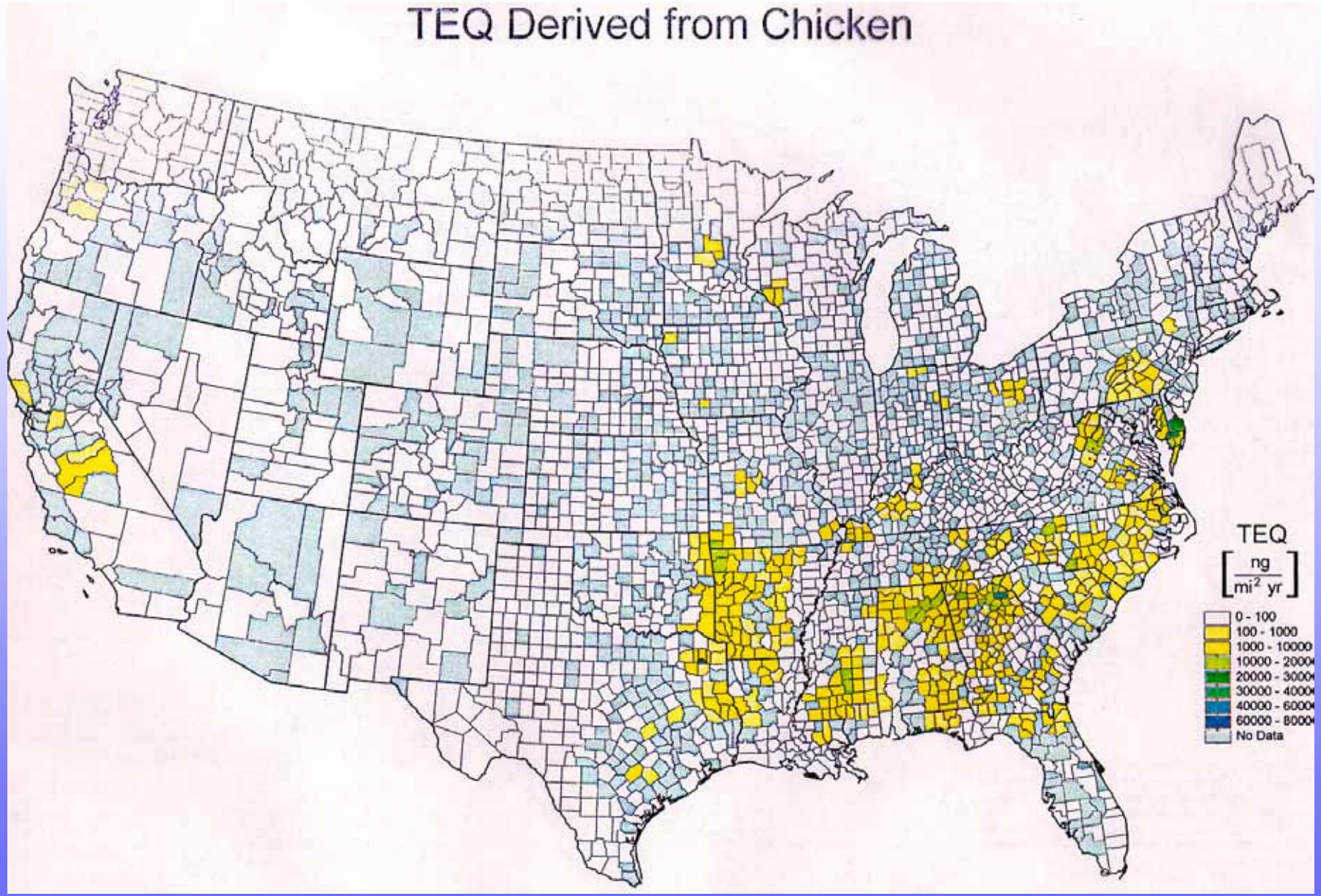
65 pg TEQ_{DFP}-WHO_{98}/day



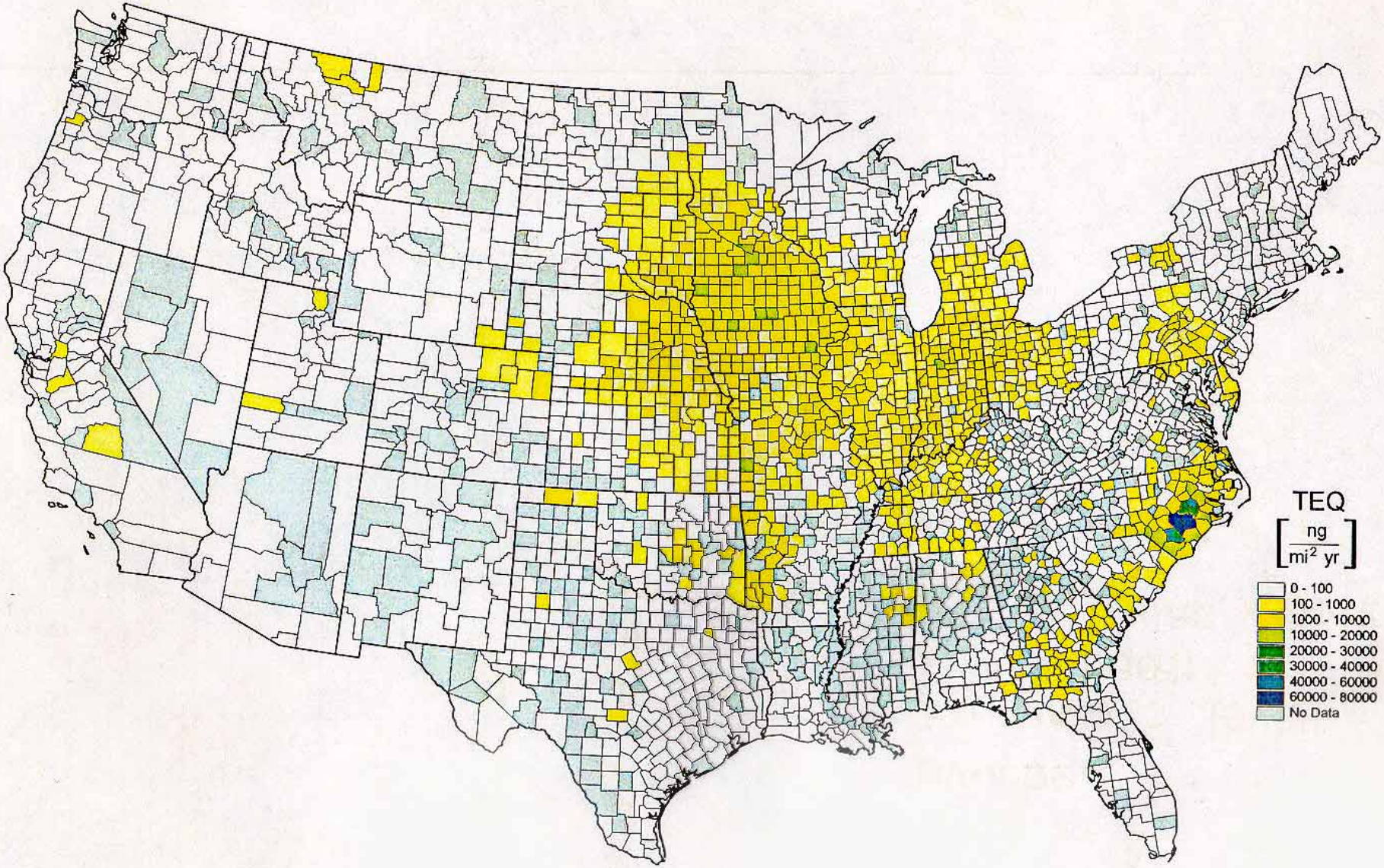
Sources and Pathways to Human Exposures



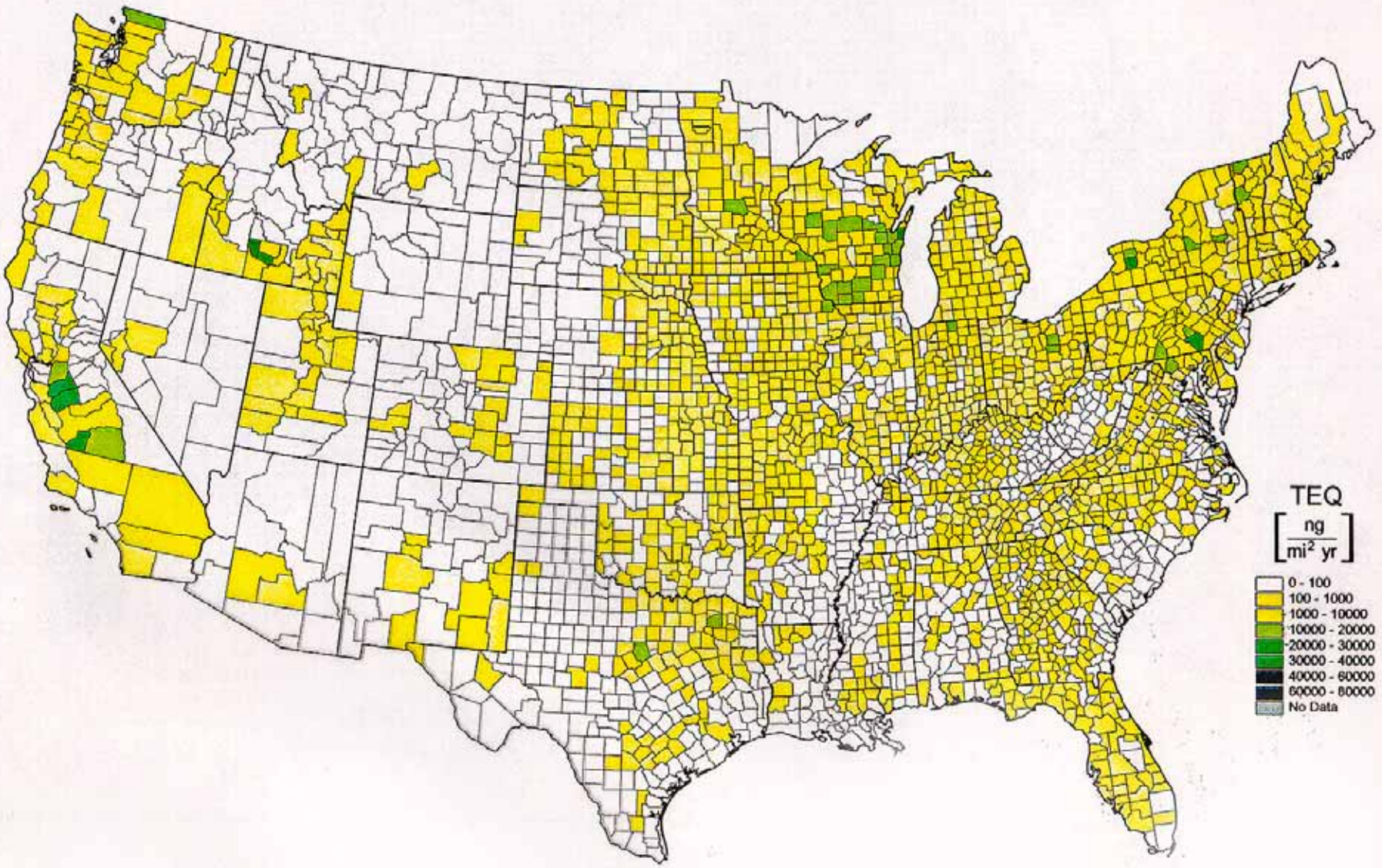
TEQ Derived from Chicken



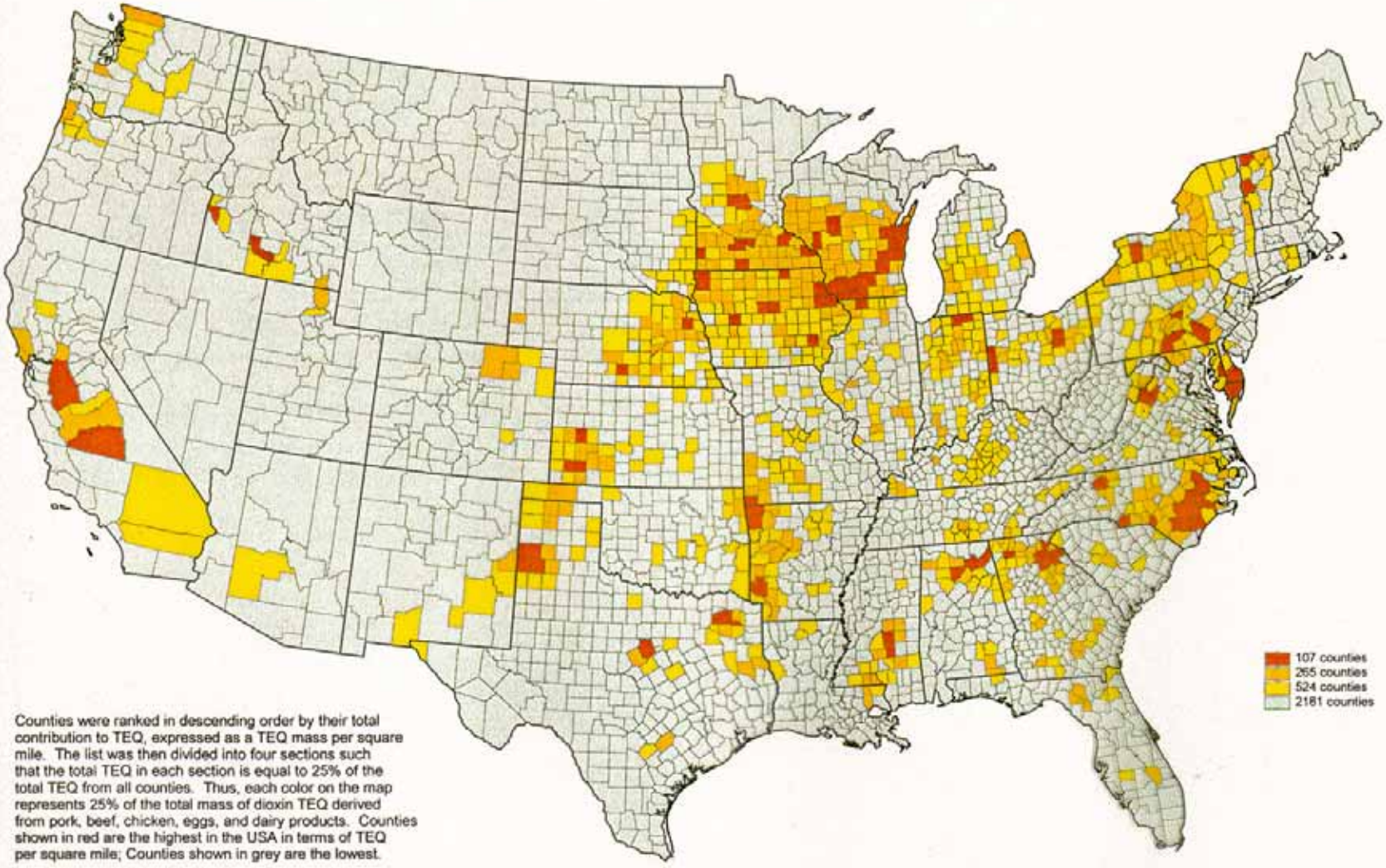
TEQ Derived from Pork



TEQ Derived From Milk and Dairy Products

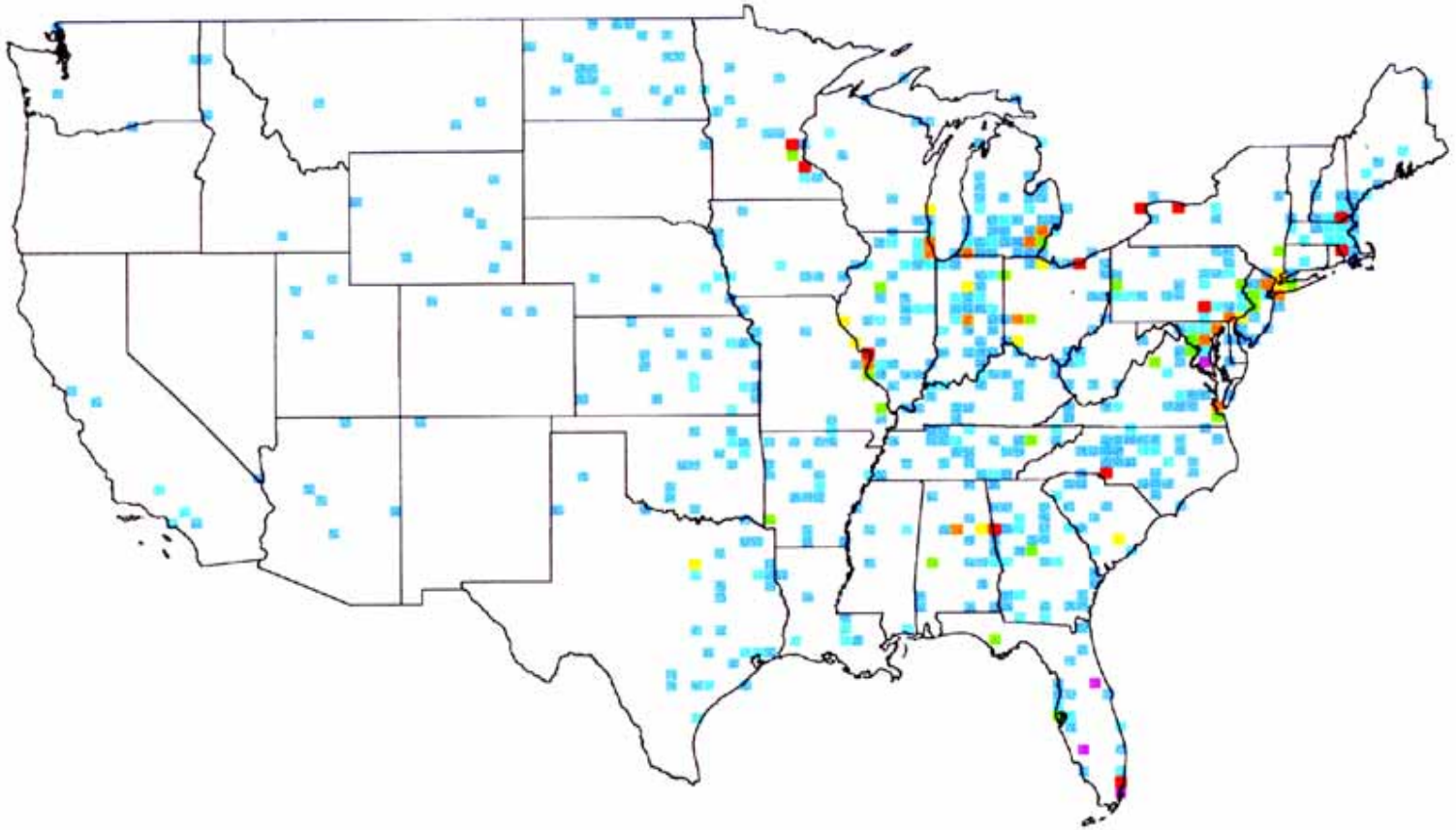


Dioxin Uptake Into Meat And Dairy



Counties were ranked in descending order by their total contribution to TEQ, expressed as a TEQ mass per square mile. The list was then divided into four sections such that the total TEQ in each section is equal to 25% of the total TEQ from all counties. Thus, each color on the map represents 25% of the total mass of dioxin TEQ derived from pork, beef, chicken, eggs, and dairy products. Counties shown in red are the highest in the USA in terms of TEQ per square mile; Counties shown in grey are the lowest.

Top 80-percent Emitting Sources, Dioxin/Furan TEQ Emissions



Units of µg/hr; number of cells in each range in ( )

- 1-10 (4)
- 10 - 100 (391)
- 100 - 500 (115)
- 500 -1000 (23)
- 1000 - 2000 (12)
- 2000 - 5000 (15)
- 5000 - 22377 (12)

N

KM

0 500 1000

ALTERNATE PATHWAYS OF EXPOSURE FOR DOMESTIC MEAT AND DAIRY ANIMALS

- **Feed additives**
  - **Ball Clay**
  - **Citrus Pulp**
  - **Recycled Fats**
  - **Mineral Supplements**
- **Environmental contamination**
  - **Penta Treated Wood**
  - **Soil Contamination**

Fluxes Among Dioxin Reservoirs